# Quantum Networking with Atomic Ensembles in the Single Excitation Regime

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**Abstract**: Quantum networks hold the promise for revolutionary advances in information processing with entanglement distributed over remote locations via quantum repeaters. We report two milestones in this direction: the conditional control of memories and the implementation of functional nodes.

In the new science of quantum information, distributed quantum networks play an important role, including for quantum computation, communication, and metrology. Considerable activity worldwide is being directed toward the development of the basic experimental requisites for enabling quantum networks. In recent years, it has been established that quantum memory is here an essential component. In a quantum repeater architecture, entanglement is distributed by swapping through a chain of entangled pairs. Without memory, all pairs need to be entangled at the same time for the entanglement distribution to succeed, an event whose probability decreases exponentially as the length of the chain increases. On the other hand, if it is possible to store the entanglement and if there is a trigger that heralds it once it is achieved, it is possible to build up the chain by entangling different parts at different times. By conditioning the evolution of the chain to the output of its parts, an exponential enhancement is attained in the probability of success.

As photons are the basic carriers of information over long distances, the necessity of using memory implies to control the exchange of information between matter and light. Great progress has been achieved for systems that could work as nodes. For example, generation of photon pairs, storage of single photons and efficient retrieval of stored single excitations were implemented with cold atomic ensembles. Heralded entanglement between ensembles was recently demonstrated in our group. A key point that has not been experimentally addressed, however, is the extent to which these techniques enable scalable networks. As underlined before, real-time control for synchronization of different systems is at the heart of quantum networking. We will report the implementation of such a conditional control for two distant memories [1]. The nodes consist of ensembles of cold atoms that can each store a single collective excitation in a probabilistic, but heralded way. As it can be transferred efficiently to a light field in the single-photon regime, the system functions as a heralded single-photon source. The control allows to store an excitation in one ensemble, while waiting for a trigger indicating the presence of an excitation in the other one. Relative to operation without control, a 28-fold increase in the probability to simultaneously generate a single photon from each system is attained. As a first application of this enhancement, we carried out a two-photon interference measurement and inferred a 90% overlap for the wavepackets.

We will then report the first implementation of a pair of quantum nodes with functionality sufficient for rudimentary tasks in a quantum network [2]. Each quantum node, L (left) and R (right), separated by 3 meters, consists of two atomic ensembles, U (up) and D (down), or four ensembles altogether, namely (LU, LD) and (RU, RD), respectively. The first step in our protocol is to prepare, by suitable measurements and conditional quantum evolution, the pair of ensembles (LU, RU) and, separately, the pair (LD, RD). After this preparation stage, the stored quantum states at the (L,R) nodes are mapped to propagating light fields, which are combined with orthogonal polarizations on each side. The states of these light fields, after filtering through local operations and classical communication, lead to photoelectric counting statistics that significantly violate a Bell inequality, demonstrating effective entanglement between the quantum nodes. Our scalable system is thereby capable of implementing entanglement-based quantum communication protocols, such as quantum cryptography and quantum teleportation.

## References

1. D. Felinto, C.W Chou, J. Laurat, E.W Schomburg, H. de Riedmatten, H.J. Kimble, Conditional control of the quantum states of remote atomic memories for quantum networking, Nature Physics **2** , 844 (2006)
2. C.W Chou, J. Laurat, H. Deng, K. S. Choi, H. de Riedmatten, D. Felinto, H.J. Kimble, Functional quantum nodes for quantum networking, submitted (2007)